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ESSAY ON FRONTOGENESIS AND FRONTOLYSIS

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Part III

Frontolysis.—Frontolysis has tended to be dismissed in meteorological literature as a mere counterpart of frontogenesis, to be explained in terms of the same deformation field. The subject is worth separate study.

We have already noticed that the frontolytic col seldom arises in practice.

Fig. 12, which shows a front, A, lying quasi-stationary between the twin centres of an intense anticyclone over England and France on February 14, 1946, probably typifies an unusually close approach to the frontolytic orientation of a front in the col. It was not at once clear whether the situation would prove frontolytic, but the intensely anticyclonic conditions ensured that the front would be quiescent. At the time of the chart shown in Fig. 12, the situation had already existed substantially unchanged for more than 24 hours, yet the front A is still marked by a sharp wind discontinuity. Eight hours later a small movement of the front west of Hurn airport brought a wind veer from NE. to S. and eventually to SW. and a sharp deterioration of visibility as the smoke from Bournemouth and Poole was transported in the direction of the airfield. At the same time, the low stratus lifted from about 500 to 1,000 ft. with the arrival of the drier continental air mass. Dew points over France were mainly between 20° and 30°F., and the dry-bulb temperatures show the effect of radiation cooling in the area of clear skies on Fig. 12, but approached the level of the warm-air temperatures in the strip of territory near the front covered by a frontal cloud sheet in the form of 10 tenths stratocumulus. Dew points in the warm air mass ranged from 42° to 48°F. and there was much fog in this air mass and at the front.

On the 15th the two high centres coalesced and it became impossible to trace the front in the central region where the surface winds fell calm and fog was widespread. Nevertheless the difference between the air masses remained, and when the continental air mass reached Brest the dew point there fell below 40°F. on the morning of the 15th. A study of the upper air temperatures over Brussels, Paris, Bordeaux and Toulouse revealed the continued existence of the frontal surface aloft throughout the life of the anticyclonic system, details on the 14th at 0500–0600 being:—

Brussels: inversion of 6°F., base 2,700 ft.
Paris: inversion of 2°F., base 2,000 ft.
Bordeaux: isothermal layer, base 2,000 ft.

It is worth noticing that the discontinuity is sharpest at Brussels in the centre of the high, where subsidence had sharpened the discontinuity surface aloft.

The surviving air-mass difference again became noticeable further west as a weak frontal line on the 16th, when the anticyclonic centre drifted away south-westwards before the main Atlantic cold front advancing from the north. Fig. 13 shows the situation at 0900 on the 16th, when drier and cooler air had reached the Scilly Isles from the west around the centre of the high, and the weak frontal line in the mouth of the English Channel marked the edge of the stratus-covered skies in the warm tropical maritime air mass still streaming eastwards through a narrowing corridor over England and Ireland towards the

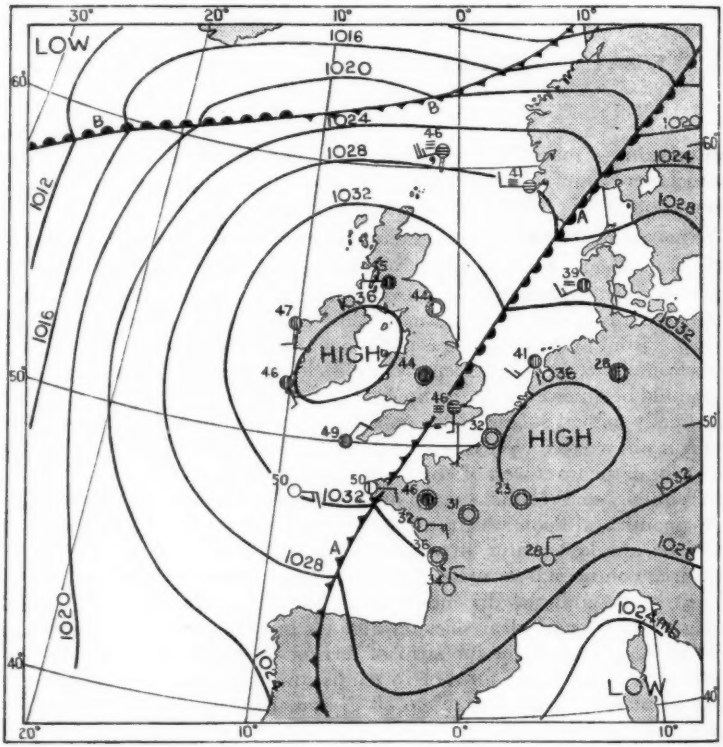

FIG. 12—SYNOPTIC CHART, 0600 G.M.T., FEBRUARY 14, 1946

Continent. R.M.S. *Queen Elizabeth* in 49–50°N. and 18–19°W. was also in the drier air mass affecting Scilly and had only broken cloud above 5,000 ft. with light westerly breezes. At the same time the weak warm front was pressing south and south-westwards over France with a belt of particularly low ceilings (300–600 ft.) and poor visibility (less than a mile) nearing Bordeaux, a major consideration for aircraft approaching that area.

Nevertheless, in spite of the way the front, in the example we have just considered, was partially regenerated after surviving several days of what have

generally been considered ideal frontolytic conditions, fronts commonly disappear from the charts. Some of them do so through a process that some American workers have called consolidation of several fronts into one. This is in reality a frontogenetic process in the sense that the resulting single front is sharpened by it. Secondary cold fronts almost habitually tend to catch up and become consolidated with the leading cold front or occlusion. Experience of Atlantic-Ocean weather analysis and forecasting shows that many of the secondary cold fronts which pass eastwards over Labrador and Newfoundland never reach Europe or the Azores as separate frontal systems, and consolidation is undoubtedly the reason for this in the vast majority of cases in winter time; in

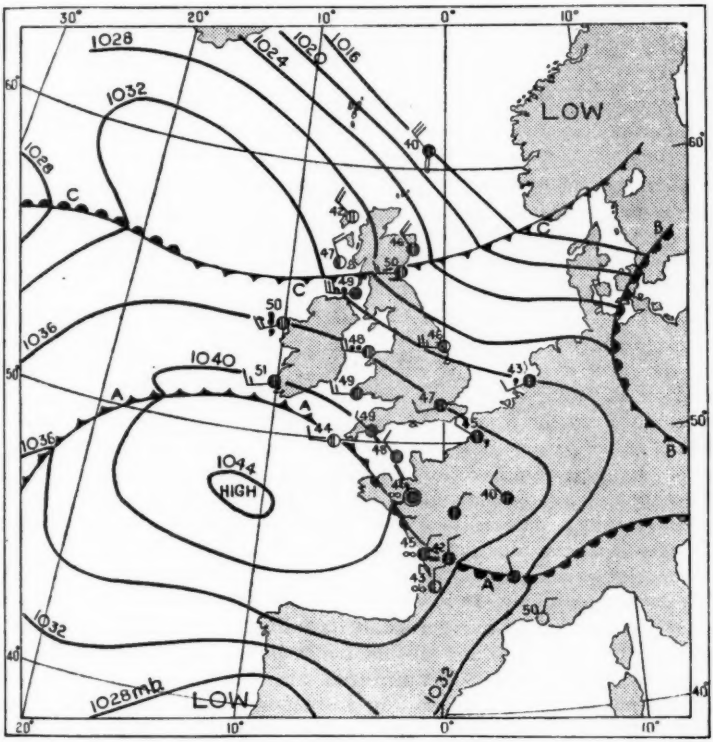

FIG. 13—SYNOPTIC CHART, 0900 G.M.T., FEBRUARY 16, 1946

summer, it is probable that a number of secondary fronts, that are little more than internal convection lines within the cold air mass coming from the north Canadian territories where ground heating is at work at this season, die away completely when the air mass is stabilized over the cool sea. The frequent occurrence of consolidation comes about through the stronger pressure gradients which are more often seen across the rearward members of a succession of frontal systems than across the foremost members, a situation of which Fig. 5 gave a typical example. Consolidation is however something quite different from frontolysis.

The fundamental condition for frontolysis is air-mass assimilation. If the air masses on either side of a given front become alike, the front disappears. Moreover this process is final; there is no special likelihood of a front ever being formed again in the same region; no transitional zone remains to favour such regeneration.

Frontolysis through air-mass assimilation will be brought about by any of the following circumstances:—

(*a*) stagnation of the air masses concerned, side by side over a single terrain, where both are subjected to like influences from the under surface and from direct radiation;

(*b*) movement of the air masses side by side along parallel tracks without any important difference of velocity between them, so that both undergo like influences;

(*c*) movement of the air masses one after the other over the same track without any important difference of velocity or shear — with a transverse orientation of the front;

(*d*) arrival of the front in a geographical region where the sense of the ground temperature gradient is unfavourable for its continued existence (this occurs where the air mass fed into the cold side of the front is as warm as, or warmer than, the air mass on the warm side; and, *vice versa*, when the warm-sector air mass encounters still warmer air ahead of it).

Cases (*a*), (*b*) and (*c*) are very similar in nature. Most rapid assimilation takes place where an adiabatic lapse rate is established. Consider Fig. 14, in which the curve of state PQRS represents a sounding through a shallow layer of cold air PQ underlying a warmer air mass RS at no very great distance horizontally from the front. This is a typical sounding for a north African station after the passage of a cold front bringing in a polar air mass from the Atlantic Ocean or from Europe, normally quite shallow in such latitudes. The effect of intense ground heating is already seen in the superadiabatic lapse rate between P and Q. At first there may have been a frontal cloud sheet of alto-cumulus or stratocumulus aloft, but, once enough rifts were made in this cloud to let the African sun get to work, the hot ground would soon change conditions in the lower layers of air. In a day or two surface temperatures of 85°F. might occur in place of the 64°F. recorded at P; and the curve P′RS would be substituted for PQRS, the former shallow polar air mass being obliterated by its entire transformation into African tropical air. The second curve LMNO in Fig. 14 is plotted from an ascent for Lisbon, Portugal (surface temperature 50°F.) after a cold front had come in from the Atlantic, and corresponds exactly to the African curve PQRS just considered. Surface heating over the Iberian peninsula to 79°F. would establish a dry adiabatic lapse rate from L′ to N and destroy the polar air mass. Finally, EFGH is the curve of an ascent made in a similar synoptic situation at Stornoway in the Hebrides. Here the prevailing humidity makes it probable that considerable amounts of convection cloud will accompany surface heating, and that the establishment of a saturated adiabatic lapse rate from E′ to G will follow from a warming of only 5°F.— from 40° to 45°F.— at the surface and destroy the colder air mass in the lower layers. The curves EFGH and E′GH also typify the development which takes place over the ocean when two air masses move or stagnate under conditions favouring assimilation.

The cases demonstrated in Fig. 14 are similar in nature to the events which led to the interruption of the subsidence surface B over Downham Market in Fig.9. It is worth noticing therefore that the interruption of the subsidence surface on the occasion referred to was to some extent a localized phenomenon, confined to places where the diurnal heating was strong enough, and, for that reason, it was possible for the continuity of the subsidence surface to be restored the following night. Similarly we should guard against assuming too readily that the first day's heating from the ground has completely destroyed a front, even over the African desert. Sections of the front over the Atlas Mountains for instance may have been much less weakened than over the open desert further south, particularly in winter if the shallow cold air has filled the shaded valleys. Activity on the front may continue for a while, or may become patchy, and the air-mass difference may take some days to disappear.

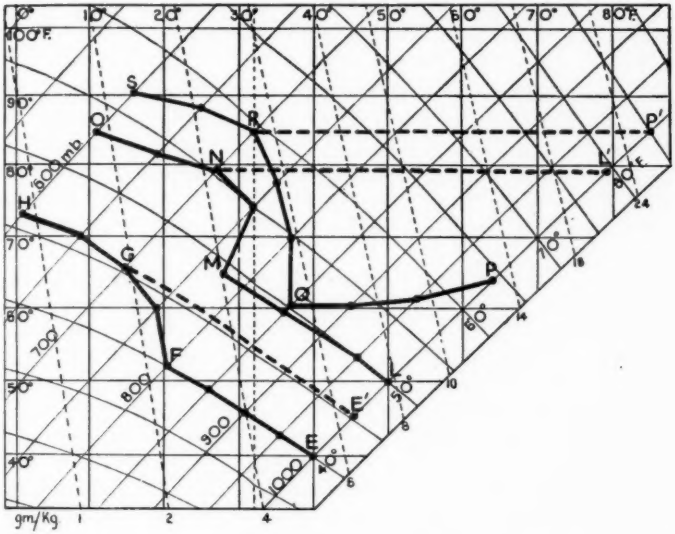

FIG. 14—TYPICAL TEPHIGRAMS OF ASCENTS OVER NORTH AFRICA, LISBON AND STORNOWAY AFTER THE PASSAGE OF A COLD FRONT

Subsidence assists frontolysis in so far as it creates the conditions of clear sky in which solar heating of the ground will be most effective. Downgliding over the frontal surface destroys the frontal cloud sheets, and turbulence cloud decks will be largely cleared away. Only moderate subsidence accompanied by strong heating from the ground should be most effective.

We may discern from Fig. 14 the conditions which favour or retard the conversion of shallow cold air masses and disappearance of the fronts and frontal surfaces which mark their limits. Great heating is needed to obliterate a cold air mass by establishing a dry adiabatic lapse rate from the surface up, but this heating is often available in Africa and, in summer, over the Iberian peninsula. Assimilation of shallow cold air masses then takes place. The shallower the cold air mass and the less pronounced the transition layer above it, the more readily

and the sooner it is assimilated. Relics of the front or frontal surface may remain here and there where the cold air mass was relatively deep or where the heating was not strong enough to obliterate it. Less heating is required to establish, from the surface up, the saturated adiabatic conditions which correspond to total disappearance of a shallow cold air mass over the ocean. Assimilation occurs in this manner under suitable conditions over the wide oceans and also over large inland seas such as the Mediterranean.

The sequence of events following the invasion of the trade-wind belt over the North Atlantic in the region of the north-west African coast and the Canary Islands by a shallow cold air mass from high latitudes is extremely interesting. Although the surface air layers show the steep lapse rate of temperature associated with strong heating from below, the existence of a stable, frontal transition layer at no great height aloft, and sometimes as low as 2,000 ft., means that the normal trade-wind cumuli disappear and give place to clear skies or to a sheet of stratocumulus, if the invading air mass is deep enough to allow condensation within it. The normal appearance of the sky, with cumulus cloud predominating, is restored after a day or two when surface heating has had time to assimilate the shallow cold air mass to tropical temperatures.

The same course of events may be followed further west over the ocean when there are sufficient observations; but weak cold fronts which have been carried around the Azores anticyclone are still liable to be noticed at Bermuda. As in other cases, the deeper the cold air mass the longer the conversion to tropical air takes.

Shallow arctic air masses are converted to similarity with the air of middle latitudes in exactly the same way in the course of long transit or stagnation over the ocean west and south-west of the British Isles, traces of the former air-mass boundary being usually discernible for two or three days.

In high latitudes air masses may stagnate over a cold surface and develop surface temperatures approximating to those of the earth's surface. Stability and absence of turbulence will however maintain discontinuities aloft. One factor working against this and tending to establish adiabatic lapse rates is the radiation cooling direct from the cloud top, frequently proceeding from completely overcast layers. It seems, however, that air-mass assimilation in high latitudes proceeds only slowly, except where the air masses are in transit over open water of considerably higher temperature. Apart from this frontolysis is a slow process in the polar regions, and old weak frontal lines with residual cloud sheets and narrow belts of fog and snow maintain their existence over long periods.

Decay of a front due to unfavourable geographical factors (case (*d*)) usually comes about through the supply of air of progressively higher temperature beneath the frontal surface. For instance, when a warm front, bringing a sector of polar maritime or tropical maritime air from the Atlantic Ocean, moves south-east across Europe in winter there comes a point at which the continental cold air ahead of the front is replaced by air modified by having been over the warm Mediterranean Sea, and, ultimately perhaps, by air that has been over Africa; the warm front is not likely to survive much of this and the air-mass difference will soon be obliterated. Similar occurrences take place with equal regularity in other parts of the world, as when warm sectors — usually partly occluded — move south-east or east-south-east across the Rockies

and encounter air from the Mexican Gulf or from the warm plains of Texas, and when old continental warm sectors reach the Atlantic seaboard of the United States in winter and meet the warm humid air brought northwards over the ocean by the Azores-Bermuda high.

A special type of frontolysis peculiar to occlusions has been described by Bergeron. At the completion of the occluding process horizontal convergence seems to set in within the uplifted warm air, accompanied by subsidence in the lower levels and lifting of the tropopause. This occurs in the former central regions of the depression where the tropopause had been sucked down. Rising pressure sets in, centred on the occlusion. The occlusion shown in Figs. 15–17 in the rear of the Skagerrak depression moved south over the British Isles on

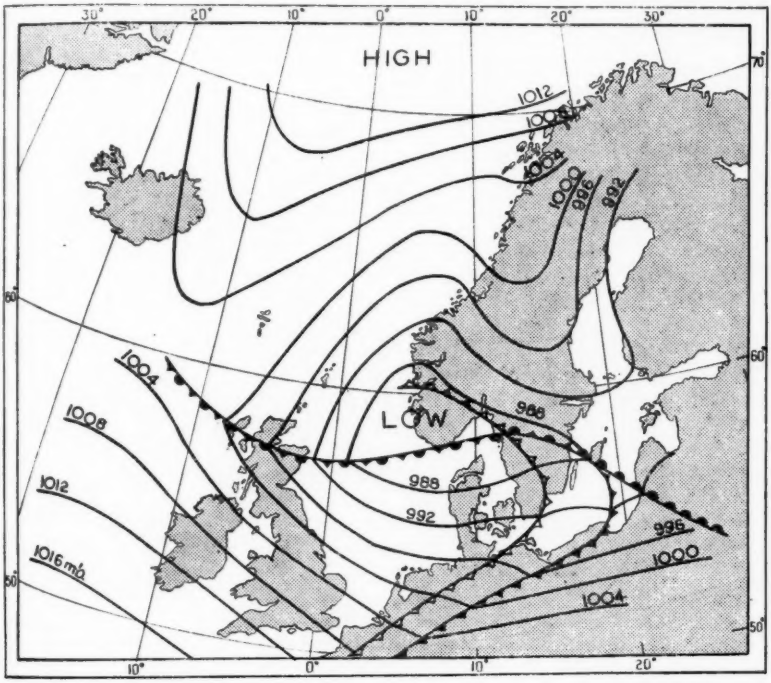

FIG. 15—SURFACE SYNOPTIC CHART, 0600 G.M.T., JANUARY 12, 1946

January 12–13, 1946, disappearing gradually under the persistent frontolytic effect of strongly rising pressures and clearing skies which helped the influence of the under surface, working alike on the two air masses moving over it. The charts represent the situation at 0600 on the 12th, soon after the pressure rises near the occlusion first became noticeable. The previously very sharp trough near the Shetland Isles has already shortened remarkably with a backing of the surface winds from E. to NNE. The association of the greatest rise of pressure (7·4 mb. in 3 hr.) with the occlusion is clearly seen in Fig. 16. The contours of the tropopause shown in Fig. 17 reveal a broad low area over the British Isles and the North Sea associated with the occluded depression centred

just further east, whilst the line of the upper front of the occlusion (trough-line of the lifted warm sector) — placed on the surface map on the basis of pressure-tendency characteristics and distribution of snowfall over Norway — corresponds to a distinct ridge on the tropopause. The front disappeared in 36 hr. A very similar synoptic situation on August 25, 1945, led to much more rapid dissolution of the occlusion moving south over Great Britain and the North Sea, probably owing to the much more effective heating influence of the ground in summer assimilating the air masses, although the isallobaric effect was a good deal weaker.

Examples are not uncommon over southern Canada in which a long occlusion trailing from a depression over Newfoundland dissolves in the section between

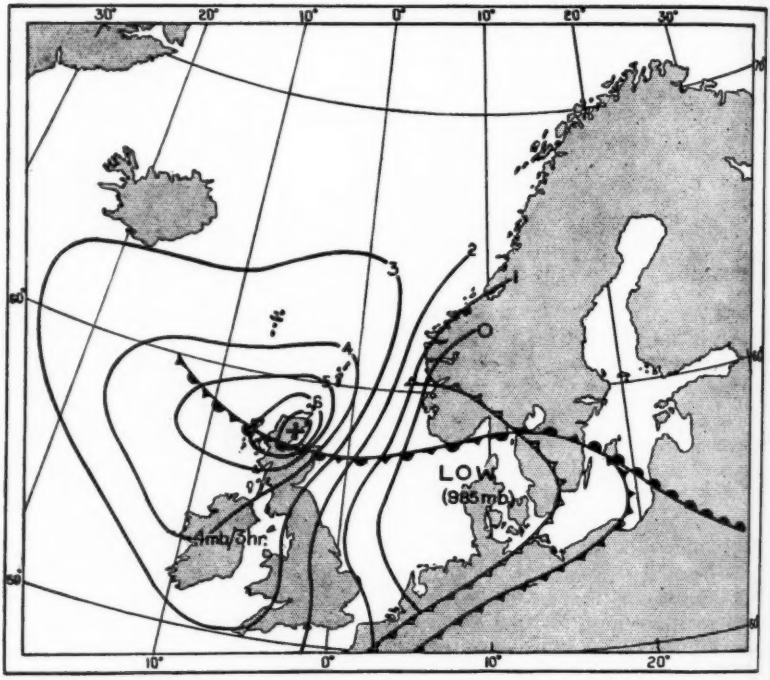

FIG. 16—ISALLOBARS, 0600 G.M.T., JANUARY 12, 1946

the depression centre and the Great Lakes, whilst the western end of the same front is maintained over Alberta as a sharp boundary between the Canadian and Pacific polar air masses. Examples have also been described elsewhere[14].

Conclusion.—We have surveyed some of the vicissitudes in the life history of fronts. Many more would come to light in any detailed study of the vertical motions and smaller circulations near the frontal surface. Nevertheless we may usefully sum up our general picture of the life history of a front.

A major frontal system is not easily formed, and, once formed, does not easily die away. In some circumstances both events do take place rapidly. More usually the frontal system travels far across the earth between its birth

and decay and undergoes successive frontogenetic and frontolytic influences, which alternately strengthen and weaken its activity. It suffers, too, continual distortions and changes of slope, as cyclonic disturbances develop and move along it. As the frontal system makes its way around the world, the nature of the air masses fed into it on either side is continually changing. The activity of the front changes in consequence, but it does not necessarily lose its identity.

The occlusions of north-west Europe advancing east and south-east across the continent may eventually appear as cold fronts sweeping across China from the heart of Asia, as has been testified by Chinese investigators[15]. Other similar systems get steered south over European Russia and the Black Sea, and

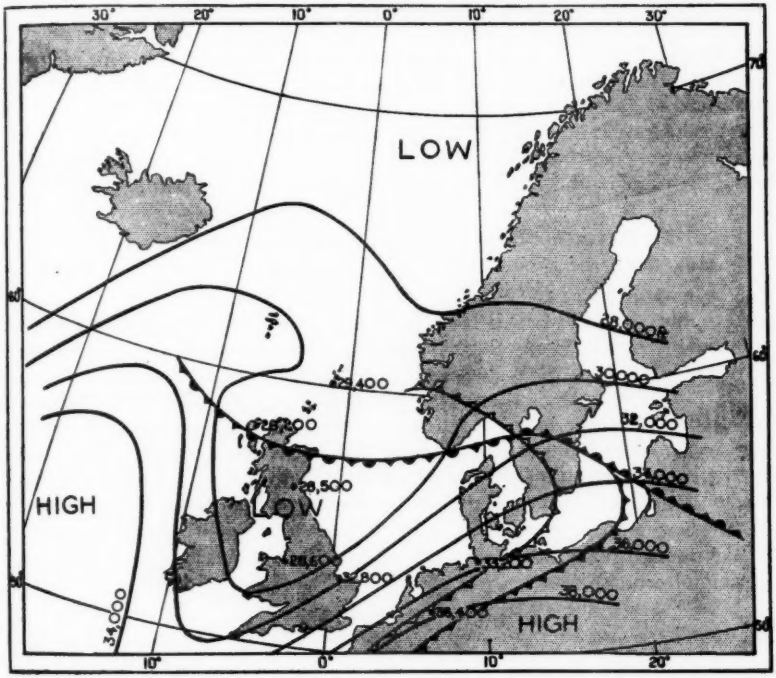

FIG. 17—CONTOURS OF TROPOPAUSE, 0600 G.M.T., JANUARY 16, 1946

arrive, usually as cold fronts, in the autumn, winter and spring seasons in the eastern Mediterranean.

We find ourselves constantly referring to these fronts emerging from their transformations as cold fronts, because the major, intercellular fronts maintained between the chief anticyclonic areas normally advance eastwards in successive stages as cold fronts and cold occlusions, the air masses in their rear being drawn from higher latitudes than the air masses ahead of them.

The frontal sequences in North America are interesting for the great frequency with which new systems enter that continent on one or other of two clearly defined courses. Occlusions, orientated parallel to the great Rocky Mountains barrier, advance on an eastward track. They represent the last stage of former Pacific-Ocean storms, but they begin a new phase of their

existence east of the mountains when deformations are induced on them, either by topographical disturbances of the wind distribution or by the influence of other circulations. In winter these are warm occlusions, and are often followed by the föhn wind, " chinook". The other dominant feature of the North-American sequences is provided by the cold fronts which come in from the arctic shores of northern Canada and sweep south or south-east across the continent east of the Rockies. These fronts, too, are believed to originate as the occlusions of depressions which have come from elsewhere, sometimes merely on a circuitous track from the Davis Strait west of Greenland around the north of Baffin Land and the Canadian Archipelago but more often on longer tracks across the Arctic Ocean. Sverdrup[16] has noticed that climatological mean-pressure charts for the winter months show a col, in the Arctic Ocean north of Alaska, between the Canadian and Siberian anticyclones with the line of frontogenesis running south-east into Hudson Bay. This coincides with (*d*)(i) in our list of geographical belts of strong thermal gradient favouring frontogenesis.* Occlusions pushing northwards through the Bering Strait from the Pacific or rounding the polar basin from the North Atlantic would be sharpened up along some such line as this, and might then strike southwards into Canada as cold fronts.

Finally, we may notice an application to the considerations with which long-range forecasters will have to deal.

The magnitude of the thermal gradients associated with each of our main geographical belts favouring frontogenesis, as well as details of their precise position and orientation in any given season, must affect the strength and orientations of the jet streams arising in association with them, and therewith the circulation index. In so far as the pattern fits a stationary wave-length appropriate to the circulation index we may expect the pattern to be stable or recurrent during that season or at that particular time of the year. This pattern in its turn will determine the prevailing locations of axes of high and low pressure on either side of the jet streams and hence the broad character of the weather over wide areas.

Acknowledgement.—I am indebted to Mr. C. K. M. Douglas for a number of helpful criticisms.

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STANDING WAVES AND POWERED FLIGHT

By H. S. TURNER, B.A.

It has been known for some years by glider pilots that the most favourable conditions for soaring are to be found in what have come to be described as " standing waves " in an air stream, and heights of well over 30,000 ft. have been reached by sailplanes circling in such waves.

Several writers have made reference to the importance of this effect to glider pilots[1], but the possible result of such waves on the flight of powered aircraft has received little attention to date. It is the purpose of this note to

*See p. 38 in Part I in the February issue.

place on record that discussions during the past two years or so with pilots operating from Northolt have revealed that the effect on powered aircraft may be very well marked on some occasions. Difficulty in maintaining prescribed heights has been reported by pilots from time to time in areas near and to the lee of high ground. Such reports have come in from Scotland, northern England, Wales, the Rhône Valley, Iberia and the south-Biscay area. The most striking instance reported at Northolt occurred on October 25, 1949, at 1130 G.M.T. over south Biscay (between 43½°N., 7°W. and 45°N., 6°W.) at about 10,000 ft. when a Viking aircraft, climbing at full power, lost 200 ft. in height in about 2 min., corresponding to a downward component of air flow of 1,100 ft./min. approximately. In general, such effects are less extreme than this example, and a more typical case would be such as occurred between Carlisle and Manchester on February 24, 1949, when height fluctuations of 500 ft. were experienced by a pilot ostensibly flying level at 9,500 ft.

It is not intended to be meticulous or exhaustive on the subject at this stage since the information which has been gathered is not in general of an exact quantative nature. However, consideration of the reasonably clear-cut cases supports the following conclusions. These are in general agreement with the account given by A. E. Slater.[1]

(*a*) Standing waves are most likely to occur to the lee of hill ranges when a stable layer of air is flowing over a shallow unstable layer. Another condition which favours their formation is a fast-flowing air stream.

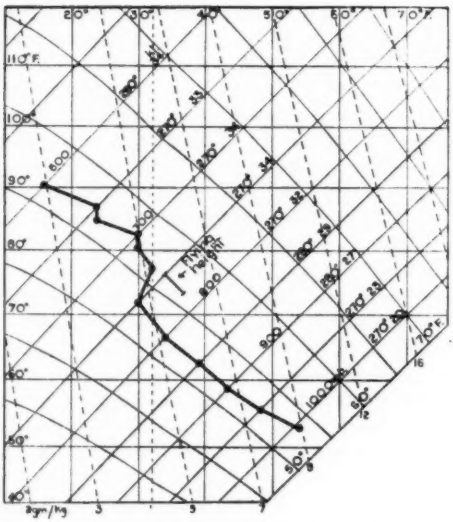
(*b*) In such conditions the air in the stable layer flows in stationary waves for some considerable distance to the lee of the hill range, the effect having been observed 60–80 miles away. The usual wave-length appears to be of the order of 5–10 miles.

(*c*) In most cases the air flow in standing waves is beautifully smooth from the flying point of view, but turbulence, if it does occur, may be very vigorous. There is some evidence to support the idea that when turbulence does occur, it is most likely in the vicinity of the crests and troughs of the waves, but more investigation is required to confirm this. The idea, however, is consistent with the type of flow envisaged by Prof. G. Manley[2] in his researches on the standing waves in the Helm wind of Cross Fell.

To date, Northolt pilots have reported twelve occurrences which were, indisputably, standing waves. Details of some of these and representative upper air soundings are given in Figs. 1–3. All occurred in areas to the lee of high ground. In seven of them it was known that the aircraft was flying in a stable layer, often nearly isothermal. In five other cases inadequacy of upper air information leaves some doubt as to the lapse rate, but in most of them stability was probable and on no occasion was it unlikely.

The depth of the lower (i.e. unstable) layer was variable, but usually exceeded 2,500 ft. and often reached 6,000 ft., this height being greater than most of the high ground from which the waves originated.

Any examination of the wind structure associated with a standing wave is complicated by uncertainty as to whether or not the area in which the soundings were taken was itself affected by the standing wave. No claim is made that the winds examined give information of anything but the general wind stream, and in this respect the conclusions would seem to have no bearing on the work of R. S. Scorer[3].



NOTES

Pilot reported difficulty in maintaining flying height.

Area—Peebles to Nottingham

Time—0845–0945 G.M.T.

Flying height—7,000–8,000 ft.

Navigator's wind—275°45 kt.

Cloud—8 oktas in banks running approximately 170–350°, thin St above and continuous with it, tops 5,000–7,000 ft. 8 oktas as above.

FIG. 1—TEPHIGRAM OF ALDERGROVE ASCENT, 0900 G.M.T., SEPTEMBER 29, 1948

The winds examined showed an average wind change of 4° and 5 kt. in the 50-mb. layer centred at the flying height, whilst the average change through the stable layer was 5° and 10 kt. It therefore seems improbable that vertical wind shear in the general stream plays any significant part in the formation of standing waves.

NOTES

Pilot reported height variations of 800 ft. despite avoiding action.

Area—Renfrew to Midlands.

Time—1800–2030 G.M.T.

Flying height—7,500 ft.

Navigator's wind—285°55 kt.

Cloud—Sc, tops to 6,500–7,000 ft.; occasional Cu to 8,000 ft.

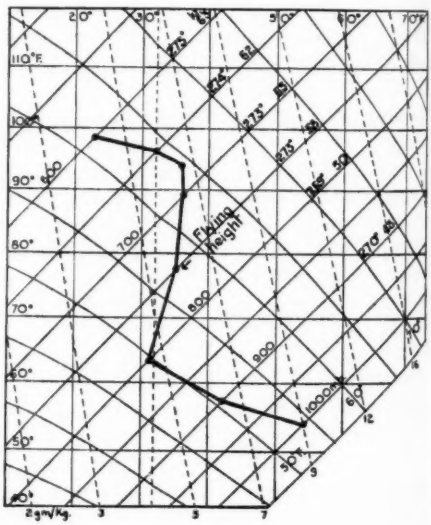
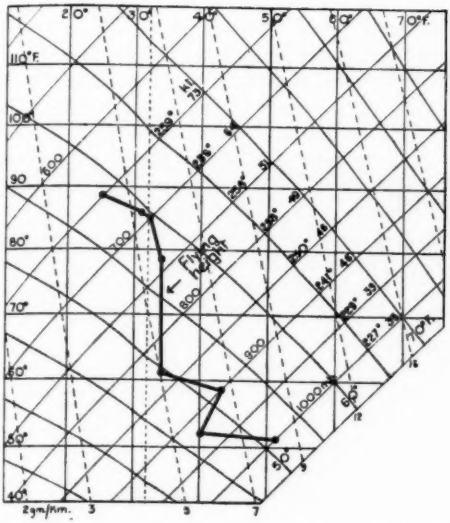


FIG. 2—TEPHIGRAM OF ALDERGROVE ASCENT, 1400 G.M.T. APRIL 20, 1949



NOTES

Pilot reported "considerable vertical motion".

Area—East Wales.

Time—1200 G.M.T.

Flying height—7,000 ft.

Cloud—8 oktas Sc, tops 5,000 ft. but 6,500–7,000 ft. over hills.

FIG. 3—TEPHIGRAM OF LIVERPOOL ASCENT, 0800 G.M.T., FEBRUARY 16, 1950

An extremely striking feature of standing waves is that they are effective to surprisingly great heights on some occasions, with the stratospheric air stream flowing, possibly, in sympathetic waves. A height of 37,500 ft. was attained in 1940 by a glider pilot[4] in a strong stable southerly air stream to the lee of the Alps. It seems distinctly possible, therefore, that at least some of the cases of clear-air turbulence reported by high-speed powered aircraft at great heights may be associated with the crests and troughs of standing waves in suitable air streams and localities.

I wish to acknowledge the assistance given me by captains of the British European Airways Corporation; in particular, Capt. T. McKenzie, whose observations prompted this study.

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METEOROLOGICAL OFFICE DISCUSSION

Temperature and humidity in the lowest hundred metres of the atmosphere

The discussion on February 12, 1951, dealt with the measurements of temperature and humidity gradient at Rye in the lowest hundred metres of the atmosphere. The opening speaker was Mr. A. C. Best.

During the early part of the war it became apparent that the temperature and humidity structure of the lowest layers of the atmosphere may have a marked effect on the propagation of the centimetric radio waves. The characteristic features of the temperature structure of the lowest layers were already well known, but there was very little information available about the humidity structure in this layer. To obtain this information electrical-resistance thermometers and Gregory humidiometers were mounted at four heights on a steel latice tower extending to a height of 350 ft. at Rye. The records obtained from these instruments over a period of three years have been analysed.

The temperature records confirmed the general features found in earlier work. During the middle of the day there is normally a lapse of temperature, the lapse rate decreasing upwards. At night there is generally an inversion. The change over from inversion to lapse and *vice versa* occurs shortly after sunrise and shortly before sunset. The magnitude of the midday lapse is greatest in summer and least in winter. It is notable that during the winter the temperature gradient in the lowest part of the region considered remains positive or zero even during the middle of the day.

Curves showing the frequencies of temperature gradients of various magnitudes demonstrate the much wider range of temperature gradient very near the surface than at greater heights in the layer considered. At all heights in the first hundred metres the most frequent temperature gradient is a lapse rate with a value between the saturated-adiabatic lapse rate and zero.

During daylight hours there is a lapse of absolute humidity in the lowest layers of the region considered, the lapse rate being greater in summer than in winter. In this respect the humidity structure is similar to the temperature structure. Similarly the lowest layer usually experiences an inversion of humidity gradient at night. In the upper part of the first hundred metres however there is usually a lapse of humidity even at night. This lapse of humidity in the region 50–100m. is small throughout the day, in fact may be zero occasionally except during the months August to October.

During the summer months both the humidity lapse rate and the absolute humidity pass through two maxima in each 24 hours, one in the early morning just after sunrise and another in the afternoon. The early morning maxima arises from the increased rate of supply of water vapour from the surface as the temperature rises. The afternoon maximum is probably caused by the action of turbulence bringing water vapour down from a region above the first hundred metres.

As in the case of temperature the frequency diagrams showed a much wider range of humidity lapse rate in the lowest layers than at greater heights, but at all levels the most frequent gradient of water vapour is zero.

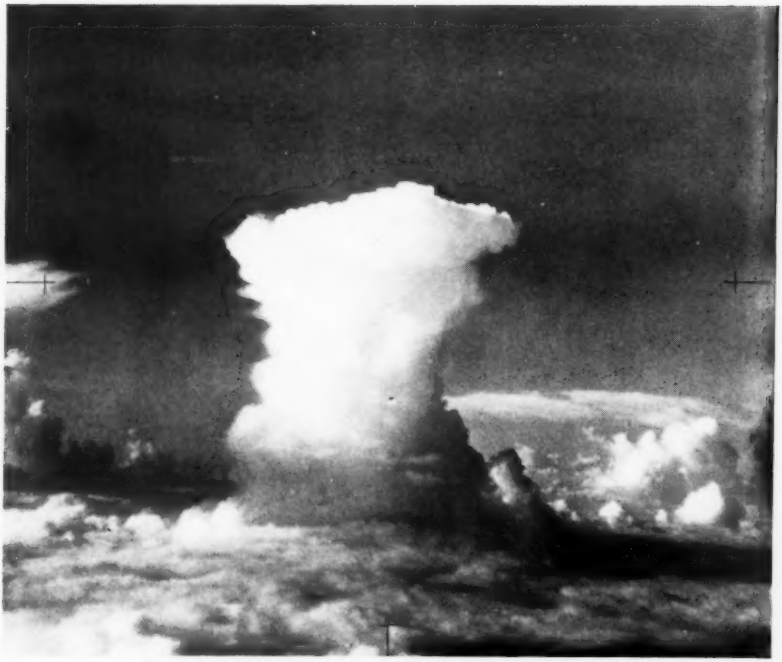
The Director, opening the discussion, asked how the humidity elements were calibrated and how stable they were. The Director also indicated that it is hoped to use the installation at Rye for an investigation of the formation of fog. Mr. Best said that the humidity elements were calibrated periodically against an Assmann psychrometer. Generally the error was two per cent. to six per cent. but the humidity element was liable to show a rapidly increasing error after six to twelve months. When this happened the element was replaced. This deterioration of the element was hastened if a very wet fog was experienced.

[*To face p. 110*

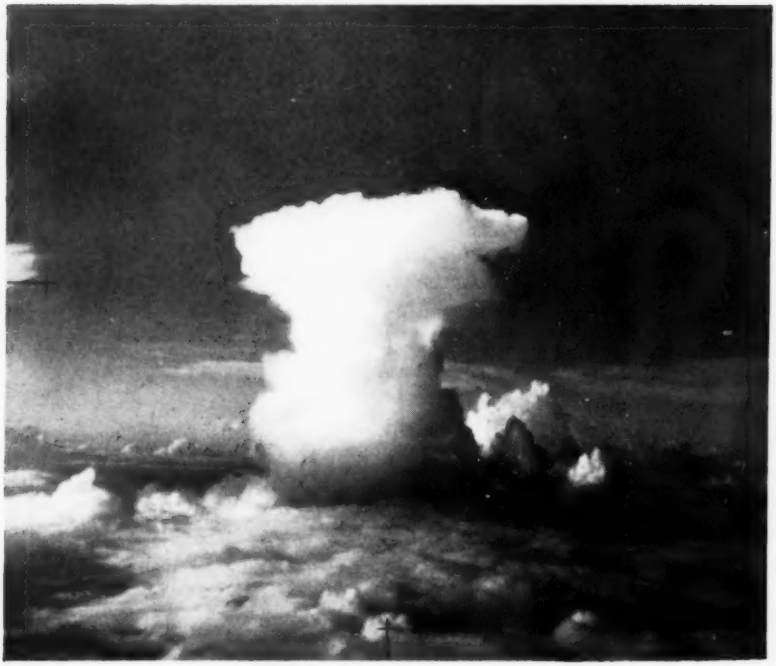
Photograph by Royal Aircraft Establishment

CONDENSATION TRAILS AND THEIR SHADOWS ON A SHEET OF ALTOCUMULUS

The photograph was taken looking westwards and upwards from the Royal Aircraft Establishment, Farnborough, at 1415 G.M.T., December 20, 1949. (see p. 119).



Near view of large cumulus developing into cumulonimbus

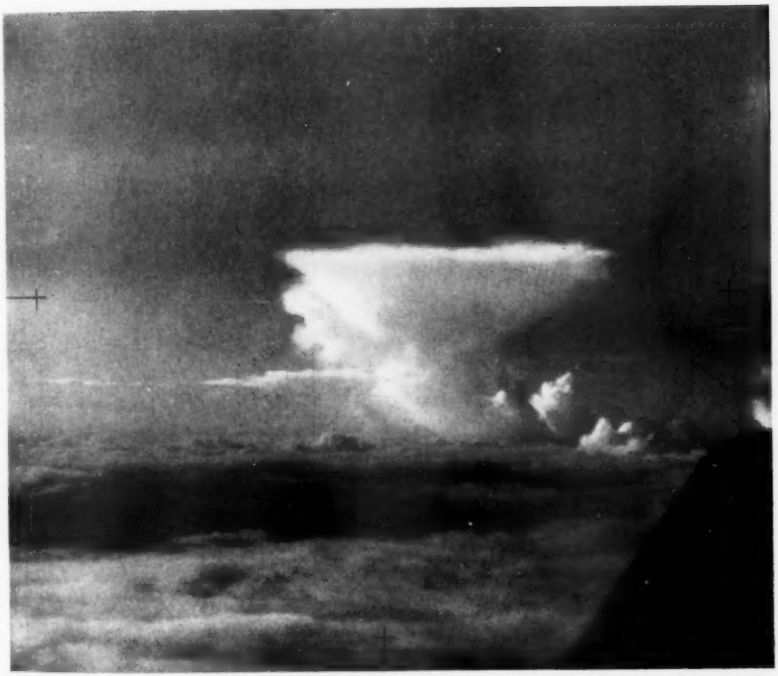


Same cloud after a short interval

DEVELOPMENT OF AN ISOLATED CUMULUS INTO A

All photographs were taken from a height

Same cloud one minute later

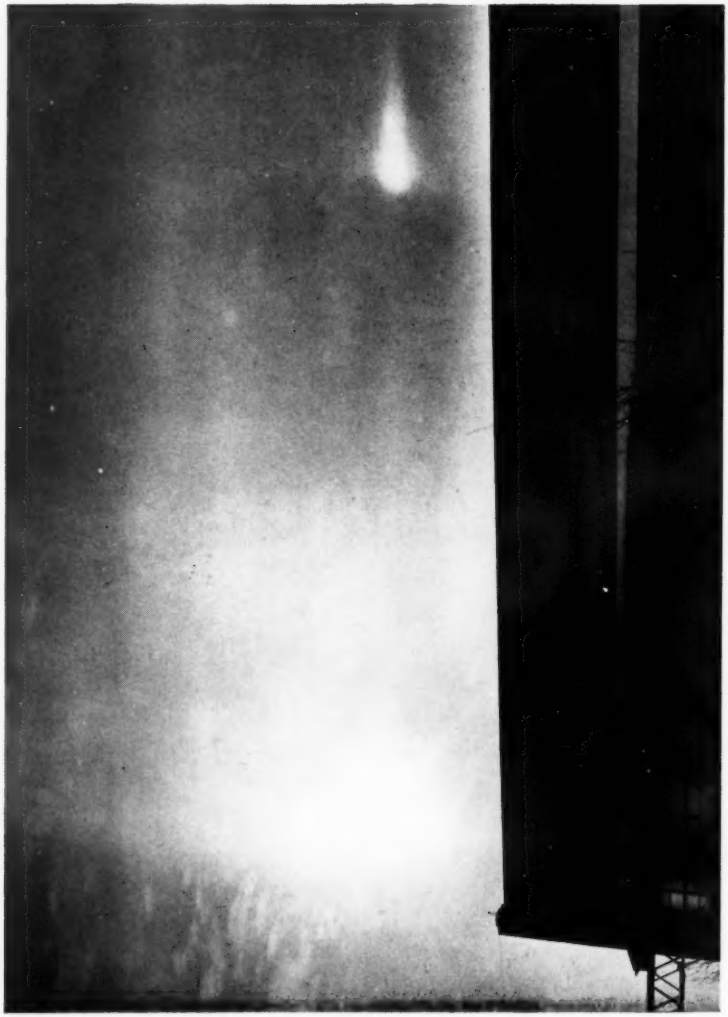


Same cloud almost fully developed, with typical anvil, five minutes after first photograph

CUMULONIMBUS CLOUD OVER THE ATLANTIC OCEAN

of 10,000 ft. (see p. 120).

[*To face p. 111*



MOCK SUN AT WEST RAYNHAM, NORFOLK, 1215 G.M.T., DECEMBER 6, 1950

Dr. Sutcliffe inquired whether this feature of the humidity elements would render the observations valueless in fog. Mr. Best thought this would not be so.

Mr. Marshall drew attention to the difference between vertical gradients of temperature in London and in the country. A comparison between readings taken on the roof of Air Ministry and at Kensington Palace frequently indicates a temperature gradient markedly different from that indicated by measurements at corresponding heights at Rye.

Mr. Sawyer questioned whether the Rye site could be regarded as a typical site. The proximity to the sea might be expected to give results very different from those obtained at inland stations. In fact a brief comparison between the Rye observations on radiation nights with observations from 24 inland stations on the same nights suggested that the Rye observations showed an appreciably lower relative humidity in foggy conditions than did observations made in an orthodox Stevenson screen. Mr. Best said that the number of observations was not yet sufficient to permit definite conclusions about the effect of the sea breeze. With regard to the accuracy of the Rye observations in fog the humidity elements are not perfect, but nor are observations made by orthodox methods.

Mr. Bigg asked if an attempt had been made to correlate temperature and humidity gradient observations with air mass. Mr. Best said not.

Mr. Knighting stressed the volume of data obtained from these observations and the fact that it will be some time before all the information has been extracted from the mass of observational material now made available by the Rye report. Qualitatively the observations raise no new problems in physics but quantitively these data must affect turbulence theory.

Mr. Gold pointed out the difficulty of understanding why the temperature of the air at 15 m. increases during a winter day if the temperature below this level does not decrease with height.

Mr. Gloyne asked whether the nature of the surroundings at Rye would justify applying the results to other terrains. Mr. Pedlow explained that in this connexion too much significance should not be attached to the term Romney Marsh. The ground round the site is not marshy, but on the other hand the vegetation never shrivels for lack of water.

Mr. L. P. Smith asked whether the proximity of the tower had any effect on the observations and Mr. Best agreed that there might be some small effect.

Dr. Robinson wondered what happened to water vapour evaporated from the ground when there is a zero lapse rate of vapour. Unlike heat the water vapour cannot accumulate to any great extent at one height. Replying to the question put by Mr. Gold, Dr. Robinson suggested that the temperature at one particular height could be raised by radiative transfer of heat.

The Director in closing the discussion emphasized the value of a discussion on new data such as had been presented.

METEOROLOGICAL RESEARCH COMMITTEE

The twelfth and thirteenth meetings of the Synoptic and Dynamical Sub-Committee of the Meteorological Research Committee were held on February 1 and 14, 1951, respectively.

At the first of these meetings, the Chairman's report to the Meteorological Research Committee was discussed, and recommendations were formulated for the revision of Part II of the Research Programme. The Sub-Committee also considered a report on zonal, meridional and other indices by A. G. Forsdyke[1] which concludes that such indices have little, if any, value in forecasting.

The second meeting was devoted to a discussion of meteorological papers. A study of the structure of warm fronts by A. G. Mathewman[2] was received with interest. A paper describing tests of the Rossby formula as applied to the movement of long atmospheric waves at the 500-mb. level by E. J. Sumner[3] was also discussed; it appears that the Rossby formula, so applied, is not a satisfactory forecasting tool. The Sub-Committee also noted papers on high-altitude photographs of clouds and the significance of strong bands of winds (jet streams) as shown by isopleths of mean winds.

[1] *Met. Res. Pap., London*, No. 591, 1951.
[2] *Met. Res. Pap., London*, No. 597, 1951.
[3] *Met. Res. Pap., London*, No. 605, 1951.

ROYAL METEOROLOGICAL SOCIETY

Dynamical methods in synoptic meteorology

At the meeting of the Society held at 49 Cromwell Road on January 17, 1951, with Sir Robert Watson-Watt, President, in the Chair, there was a discussion on dynamical methods in synoptic meteorology. The opening speakers were Mr. F. H. Bushby, Mr. E. J. Sumner and Dr. R. C. Sutcliffe.

Dr. Sutcliffe set the tone of the discussion and provided a theoretical background. He was only concerned with those dynamical theories which up to now had actually been applied to forecasting problems, and briefly described in simple terms two approaches. First, the Rossby theory in which the atmosphere was treated as an incompressible barotropic fluid, the absolute vorticity being conserved. In such an atmosphere there were no energy sources, and the theory only dealt with the inertial characteristics of the flow. The earth's atmosphere was of course far from barotropic in middle latitudes but Charney had argued that the theory could nevertheless be applied to a mean state, the flow patterns being averaged vertically to give an "equivalent-barotropic" flow corresponding roughly to the actual flow at about 600 mb., the so-called equivalent-barotropic level. Work along these lines was still in progress in America.

His own approach was to deal with the vertical and horizontal distribution of divergence in the atmosphere[1] and related development (vertical motion) to the thermal field. As Sawyer had indicated[2] the two theories were in a sense complementary. An example was shown of the agreement between the computed field of development and the change in the surface pressure field.

Mr. Sumner then described his paper on "The significance of vertical stability in synoptic development"[3], which entailed the addition of a further term to Dr. Sutcliffe's well known equation. This term is equal to $\beta \nabla_p^2 (\overline{\Gamma_p dp/dt})$ where β is a positive constant for the isobaric layer under consideration, ∇_p^2 is the Laplacian operator $\partial^2/\partial x^2 + \partial^2/\partial y^2$, Γ_p is the departure of the actual lapse rate of temperature γ_p, referred to a pressure scale (i.e. $\partial T/\partial p$), from γ_a the wet- or dry-adiabatic lapse rate, whichever applies, and dp/dt is proportional to the

vertical velocity relative to a (moving) pressure surface. The bar over the product denotes a mean value taken vertically throughout the layer in question with respect to a logarithmic pressure scale.

The above expression represents the isallobaric divergence effect due to the dynamical (adiabatic) temperature changes associated with an organized field of vertical motion. It opposes the development both of cyclones and anticyclones when the atmosphere is stable. For instability in depth, which could only arise in the case of cyclonic development, the development would proceed very rapidly. The magnitude of the effect was shown to be directly proportional to the stability parameter Γ_p and inversely proportional to the square of the Coriolis parameter and the square of the dimensions of the pressure system. Small systems could hardly be expected to develop at all in a stable atmosphere, especially in low latitudes.

Secondly, Mr. Sumner gave a few results of a test of the Rossby wave formula based on one year's 500-mb. charts, and of an attempt to apply it numerically in short- and medium-range forecasting. Only wave trains comprising at least two troughs separated by a ridge were considered, the individual members being far from sinusoidal in many cases. A correlation of 0·90 (38 cases) was obtained between the actual 24-hour displacements of troughs at 500 mb. and estimates based on the Rossby formula, after certain random errors of drawing and measurement were smoothed out. Also the zonal velocity and wavelength parameters were shown to be important individually. These results only applied to the cool seasons (winter and spring), and provided some hope of being useful in forecasting practice. Further results for the warm seasons were considered to rule out this possibility.

The Rossby equation, modified by the appropriate regression coefficients, was applied to another period, and the results obtained compared with those achieved in routine forecasting (short- and medium-range) at the Central Forecasting Office, Dunstable. However, this comparison indicated that no improvement on the standard of accuracy at present attained in routine forecasting can be expected by an application of the simple Rossby formula. In spite of this Mr. Sumner thought that the equivalent-barotropic theory may give a useful first approximation in certain cases and for a limited time ahead, provided a not too simple model of atmospheric flow was adopted. Numerical integration from observed stream-line patterns in the manner suggested by Charney was one way which might repay the effort.

Mr. Bushby was concerned with the application of numerical methods to normal synoptic practice, and said that, although the time when all the forecaster's prebaratic and prontour charts could be done numerically may be far distant, some progress had been made in recent years.

He described two series of tests which had been made in the Forecasting Research Division on Charney and Eliassen's method[4] for predicting 500-mb. contour maps 24 hours ahead, which showed fairly conclusively that the results obtained were not quite as good as those obtained by conventional methods, although the predictions of the movement of the troughs and ridges at 50°N. were slightly better. Mr. Bushby stressed, however, that more refined methods based on less restrictive assumptions were being developed which might show more promise. Attempts by himself to improve the one-dimensional method of

Charney and Eliassen were still being made; the results so far obtained provided corrections of the right sign but of greater magnitude than was required to make the forecast accurate.

Another recent development was an adaption of Sumner's equation to give a numerical solution by relaxation methods for the mean vertical velocity over a wide area in the 1000–500-mb. layer. The technique was still being improved, and so far only one case had been worked out. For this case the mean vertical ascent in the vicinity of a depression over the British Isles could account for the amount of rainfall which in fact occurred in the area, using Bannon's method[5] for estimating the rainfall.

In the ensuing discussion Dr. Scorer said that a barotropic atmosphere had no energy source and no developments could take place. Results obtained by such assumptions could easily be 50 per cent. out. Dr. Sutcliffe's theory was also " inertial " but had the merit of taking account of divergence and convergence which were important. He considered that Rossby waves were necessarily stationary waves, and that linear extrapolation would give as good results as barotropic formulæ and quadratic extrapolation better. He also mentioned that the idea that the stability of the atmosphere was important was not new in meteorology.

Mr. Galloway asked at what stage the surface pressure came into the argument, and Mr. Pearce questioned the philosophic basis of the " thermal-development " approach.

Dr. Sutcliffe, in reply, expressed considerable doubts as to the applicability of barotropic theory, but admitted to a cautious optimism as regards developmental ideas. He said that surface developments were implicit in the theory. Mr. Sumner said that Cressman[6] had given figures which showed slightly better results for the Rossby formula than linear extrapolation. Moreover, in practice, one often had to deal with newly formed waves with nothing on which to extrapolate. In his opinion Rossby waves could be either moving or stationary; implicit in the theory (and explicitly in some papers) was the assumption that the field of pressure could and would accommodate itself to the prescribed field of motion of the particular model adopted. The movement of waves whose wave-length differed from the stationary wave-length was presumed to be accomplished by such a process of accommodation, the divergence and convergence associated with the pressure changes producing relatively small changes in the vorticity distribution.

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ROYAL METEOROLOGICAL SOCIETY AND INSTITUTE OF ELECTRICAL ENGINEERS

Symposium of papers on electrical meteorological instruments

A joint discussion meeting was held at the Institute of Electrical Engineers, Savoy Place, on January 30, 1951, beginning at 3.0 p.m. The meeting was divided into two parts: in the first part, before tea, with Dr. G. A. J. Sowter in the Chair, the following papers were read:—

Hartley, G. E. W.— The development of electrical anemometers

Mr. Hartley confined his paper to the development of cup anemometers and wind vanes. Early standard anemometers were calibrated to make an electrical contact for each twentieth of a mile run of wind. Later improvements consisted of changing the shape of the cups from hemispherical to conical to reduce over-estimation produced by gustiness, better bearings, introduction of a cam-operated mercury switch, and insertion of a device for ensuring that, at low wind speeds, an electrical contact is only maintained for a short period. Such anemometers are suitable for measuring the wind over short timed periods. They can be made to record automatically by connecting the contact inpulse mechanism to a telephone message-register or similar electromagnetic counter and photographing the count at regular known intervals automatically (this was the basis of a design by E. L. Deacon); or by letting the impulses lift the pen arm of a suitably graduated recorder by equal small amounts, the pen being allowed to drop at short intervals (3 min. in the Bibby recorder), when the chart drum moves on slightly; or by letting the impulses rotate a chart drum along which a pen carriage moves at constant speed, time being measured by automatic time marks at regular intervals. Mr. Hartley then spoke of new developments in cup-generator anemometers and showed a photograph of the latest type. The main difficulty in such an anemometer was the lag in response of the generator at low speeds, although with a recording a.c. voltmeter it was easy to record the wind between 6 and 90 kt.

Mr. Hartley also described electric wind vanes with remote indicators showing wind direction to 8 or 16 points by means of lights. To overcome the difficulty of recording wind changes of direction exceeding 360° it was necessary to use a recorder of the Baxendell type, where the pen has to move over the joint in the paper without catching in it, or to use a cam or system of cams, or to use the familiar Dines twin-pen system which requires considerable torque. The two-cam system required least torque and was in use in a bi-directional wind vane connected by magslip transmitters to the direction recorder.

Rosenbrock, H. H. and Tagg, J. R. — Wind- and gust-measuring instruments developed for a wind-power survey

Mr. Rosenbrock opened his paper by remarking that, for the purpose of siting wind-driven electric generators, it was necessary to know the wind conditions at windy sites which are not typical of most areas, and in particular the effect of gustiness on windmill blades. Mean wind speed was first obtained from a standard Meteorological Office cup anemometer connected either to a photographic recorder, similar to E. L. Deacon's, or later, to an impulse recorder making dots on a moving chart. Gusts, after consideration and rejection of a hot-wire anemometer, bridled-cup anemometer, cup-generator,

windmill anemometer, pressure-tube anemometer and plate anemometer, were finally measured by allowing the wind to blow against a perforated aluminium sphere held up by an almost vertical rod pivoted at its middle. The bottom of the rod is attached by a steel wire to a spring diaphragm, the deflexion of which is approximately proportional to V^4 at low speeds and $V^{4/3}$ at high speeds (V=wind velocity). The deflexion was measured by a mechano-electric transducer which takes the form of a miniature triode which is usually operated with the grid connected to the cathode. Mr. Rosenbrock showed a few records of this anemometer, chart speeds of which may vary from $\frac{1}{2}$ in./sec. to 6 in./sec. A 1 in./sec. speed was found sufficient to show all the detail in the records, the faster speeds being used to find the response of the anemometer. The response was complete in about 0·07 sec.

Hawkes, H. D. and Laws, J. M.—An electrical method of resolving true wind velocity aboard ship

A sinusoidal voltage or current can be represented by a simple vector, and, if a number of alternating quantities of the same frequency act at the same time in a given circuit, their resultant is given by their vector sum, just as in the resultant of a number of co-planar velocities. Mr. Hawkes showed how, in the Elliot wind recorder, an electric vector representing apparent wind aboard ship, by means of a resolver, is combined with a similar vector representing the ship's velocity to produce automatically the true wind speed and direction on remote indicators and recorders.

Bell, J. and Langham, E. M.—Mean-wind-velocity instruments for use on naval craft

Mr. Bell described two instruments, both using mechanical computing and transmitting devices, the first to indicate continuously the mean direction of the apparent wind and the second to indicate the true force and direction of the wind, regardless of the speed and direction of the ship, and further to obtain the mean apparent wind force and direction. The instruments are suitable combinations of magslip transmitters and resolvers, induction potentiometers and generators, and servo motors connected together mechanically or electrically. The induction potentiometer has a toroidal winding round a magnetic-core ring so that when a load is taken from a subdividing point the accuracy of the divided voltage can be relied upon to within 0·1 per cent. and the whole winding is still available for other purposes. The remaining devices are rather like generators or motors, except that the rotors and stators do not always have the same phase windings — for instance a magslip transmitter has a single-phase rotor and a three-phase stator, and a servo motor has a three-phase rotor with an external resistor carried on a spindle and a stator with a two-phase winding, one from a mains supply and the other through an electronic amplifier.

The discussion on these four papers was opened by Sir Nelson Johnson, who said that the Meteorological Office would like help from electrical engineers in the design of instruments; he stressed that meteorological requirements included a measure of the lack of uniformity (such as gustiness) — patchiness he would prefer to call it — over the whole scale of phenomena extending

down to the small micrometeorological scale in units of millimetres and hundredths of a second and right up to air-mass phenomena in units of 100 Km. and days. This was a range of 10^8.

Sir Nelson was interested in the perforated-sphere anemometer and thought the transducer could be applied in a number of ways; he would like to know the period of response of the anemometer in a gusty wind. Other speakers thought that the hot-wire anemometer had been dismissed too readily. Prof. MacGregor-Morris said that he had tried to produce a portable instrument some forty years ago with wires enclosed in a circular rod and showed a photograph of the instrument in use at Happisburgh Lighthouse in 1912; it was sensitive to low velocities. Another speaker suggested that a frequency type of coupling might be used to reduce friction losses in a recording instrument and mentioned the idea of a toothed wheel being observed through a gap.

Mr. Rosenbrock replied that the perforated-sphere anemometer would measure down to 20 m.p.h. but there was a natural frequency in one part of about $\frac{1}{12}$ sec.; the recorder would not respond in less than $\frac{1}{10}$ sec. for it overshoots. He also said that the hot-wire anemometer needed repeated calibration because of the collection of dust on the wire, and the time of response would be increased if it was enclosed in a tube. In reply to Dr. Scrase, Mr. Bell said that damping of the wind vane had not been used in measuring the mean wind because of the different forces available in a wind of 2 m.p.h. and 60 m.p.h. It had been thought better to use a mechanical governor in the transmission, thus controlling the speed of response.

After tea, Sir Robert Watson-Watt took the Chair and the following papers were read:—

Jones, F. E., Hooper, J. E. N. and Alder, N. L.—The radar-sonde system for the measurement of upper wind and air data

The slant-range obtained in wind measurement by radar with the normal corner reflector is of the order of 30 miles. Much greater ranges can be obtained by using an airborne transmitter. Dr. Jones showed how this has been achieved with a transponder which receives impulses from the ground station in the range 151–154 Mc./sec. and retransmits them in the 2,700–2,900-Mc./sec. region (10·7 cm. wave-length). At the same time it is possible to signal back the readings from the usual meteorological elements. The whole radar-sonde, together with batteries, container, telemetering unit and switches weighs only $4\frac{1}{2}$ lb. of which the batteries account for 3 lb. All except the arials and the temperature and humidity elements are enclosed in a non-conducting onazote container 1 in. thick. Since this is not quite air-tight and the valves generate enough heat in ascent to keep the inside within a few degrees of room temperature at all heights, it is possible to measure pressure inside independently of temperature and also to telemeter information roughly ten times more accurately than with radio-sonde. The switch to bring each element, in turn, into the circuit completes a cycle in 15 sec.—3 sec. for each element and a reference —and is based on a telephone meter. The ground station contains a transmitter, a master calibrator, a receiver, a wind computor, a pulse-code demodulator, and a recorder of pressure, temperature and humidity — all working automatically and including magslip resolvers and electrical pulse counters.

Dr. Jones thought that, with mass production and the saving of some ground personnel, it would be possible to achieve a cheaper upper air sounding than with the present radio-sonde system.

Brewer, A. W. and Dobson, R. H.—An automatic frost-point hygrometer for measurements in the upper air

Dr. Brewer described an effort to make the Dobson-Brewer frost-point hygrometer fully automatic. The cooled thimble is watched by a photo-electric cell which, by a suitable electric circuit, controls additional heating of the thimble (it is normally over-cooled) until the growth of hoar-frost crystals on the thimble is constant and equal to their sublimation. The temperature of the thimble (which is measured by a thermocouple) is then the frost point of the air sampled. Although the apparatus had worked successfully in the laboratory, defects, still unresolved, had been found in aircraft use.

Pratt, A. W., Collins, B. G., Lacy, R. E. and Spink, E. W.—Some meteorological instruments used in building research

Mr. Pratt described meteorological instruments developed at the Building Research Station. The first of these was concerned with measurements of the ventilation rate of buildings; it had been found that in winds below 4 or 5 m.p.h. the rate of ventilation depends on the temperature difference between the outside and inside and at higher speeds on the wind velocity. The wind-run analyser is an electrical circuit operated from the standard Meteorological Office cup anemometer which makes a contact twenty times per mile of wind run. The analyser counts the contact with a system of relays over hourly intervals and records the count on a chart.

The second instrument was the directional wind recorder which consisted of a cup anemometer with contacts, an 8-way switch driven by a wind vane and a set of electromagnetic counters. The signals of the anemometer are distributed by the direction switch to the appropriate counters, and so the device counts the wind run from the 8 directions and also the total run. The contacts are arranged so that each contact of the cup anemometers records through only one directional switch even though the vane swings to another direction during contact.

The third instrument was the equivalent-air-temperature recorder, which is designed to record an air temperature taking into account heat loss or gain by radiation and convection, for calculation of heat flow through walls from the conductivity formula; it is the temperature of the wall when exchanging heat freely with its surroundings and no heat is flowing through it. The instrument is a cube with four vertical graphite receiving surfaces and one horizontal one facing upwards. The temperature of each graphite receiver is recorded by a thermopile arranged to record the difference between the temperature of the surface and the temperature in a screen slung under the apparatus.

The fourth apparatus was developed for the measurement of temperature and the calculation of mean temperature at a number of points inside experimental buildings. The apparatus records the readings of a number of resistance thermometers at 44 separate points and sums 100 readings a week at each point. It is built up of an arrangement of uni-selectors.

In the course of the discussion, Prof. Sheppard referred to the value of instruments such as the radar-sonde to meteorologists, and their appreciation of the designer's difficulties. Dr. Scrase and Dr. Harrison dealt with calibration pointing out that a more costly instrument which did not require individual calibration might well be cheaper in use.

Dr. Harrison also said that a hypsometric method of measuring pressure in the free air was being considered, and that he was not sure of the effectiveness of the radar-sonde container in maintaining constant temperature; Dr. Hopkins asked if there would be site-errors for the radar-sonde; Mr. Humphreys suggested that a continuous-wave radar system might be cheaper for wind measurement than a pulse system; and Mr. D. D. Clark thought the rate of ventilation of the Dobson-Brewer hygrometer was more important than Dr. Brewer had suggested as it made a difference to the rate of growth of crystals.

In reply, Mr. Lacey said that the Building Research Station had considered existing instruments before designing new ones; Dr. Brewer was doubtful about increasing the ventilation of the the frost-point hygrometer at low temperatures because of the amount of heat brought in by the air; Mr. Hooper said the radar-sonde was a compromise between cost and accuracy, that the telemetering circuit was the only part needing calibration and that there was adequate leakage of air through the container.

METEOROLOGICAL OFFICE PUBLICATION

The following publication has recently been issued:—

METEOROLOGICAL REPORTS

No. 8—Upper air analysis and tropical forecasting. By R. A. S. Ratcliffe, B.A.

This report is an attempt to bring out the uses of upper air analysis in relation to tropical forecasting. Attention is focussed mainly on the 1000–500-mb. thickness chart and on the 700-mb. contour chart. The report is based on data available in south-east Asia in 1945.

The characteristic upper air patterns before and during the SW. monsoon periods over India and the adjacent areas are discussed, together with some day-to-day changes in patterns which can be correlated with the weather. Various miscellaneous applications of upper air charts to synoptic forecasting in the tropics are suggested.

NOTES AND NEWS

Condensation trails

The photograph, facing p. 110, of condensation trails and their shadows on a sheet of high altocumulus was taken at the Royal Aircraft Establishment, Farnborough, at 1415 G.M.T. December 20, 1949. The camera was pointing to the west and upwards.

We are indebted to Mr. T. H. Applegate, Meteorological Officer at Farnborough, for drawing attention to this photograph and to the Ministry of Supply for permission to reproduce it.

The interesting question, as Mr. Applegate realized on seeing the photograph, is whether the condensation trails were on the near or far side of the cloud sheet so that their shadows were projected on to the lower or upper surface of the cloud sheet.

The elevation of the sun above the horizon at the time was approximately 10°. From this it follows that the trails were above the cloud unless the cloud sheet was sloping upwards to the south-west at such an angle that its slope in the direction from the trails to the sun exceeded 10°. It seems unlikely that the sheet was sloping at so steep an angle. It is by no means unknown for cloud to be seen through a thin sheet of cloud. The International Cloud Atlas has a photograph, Plate A 22, of cumulus cloud seen through altocumulus translucidus. Condensation trails seem brighter than thin altocumulus particularly when seen by the light from a low sun. A condensation trail was clearly seen through altocumulus from Harrow at 1615 G.M.T. on October 10, 1950, a time when the position of the sun is much the same as at 1415 G.M.T. on December 20.

Development of a cumulonimbus

The four photographs in the centre of this magazine were taken from a height of 10,000 ft. at approximately one minute intervals on July 31, 1943, by the crew of an aircraft from St. Eval when returning from a meteorological reconnaissance flight, in a position 100 miles south-west of Ireland. They show the the development of a rather solitary cloud protruding through a layer of cumulus cloud, the top of the layer cloud being almost 10,000 ft.

OBITUARY

Captain L. A. Brooke Smith, R. D., R.N.R.—Captain L. A. Brooke Smith, Marine Superintendent of the Meteorological Office from 1919 to 1938, died at his home in Suffolk on December 21, 1950, aged 72.

Louis Alfred Brooke Smith, son of a master mariner, was born in Cape Colony and educated in the Colony and in the school ship *Conway*. After apprenticeship and two years Royal Naval Reserve Training he qualified as Extra Master in 1903 and joined the Orient Line. He received rapid promotion and was appointed to command R.M.S. *Omrah* in August 1913. During the war of 1914 to 1918 he rendered distinguished service in the Royal Navy, rising to the rank of Commander, R.N.R.

On demobilization from the Royal Navy in 1919, Commander Brooke Smith was appointed Marine Superintendent of the Meteorological Office, which post had become vacant by the death of Captain Campbell Hepworth, C.B., R.D., R.N.R., Commander Brooke Smith had always been a keen observer for the Meteorological Office, as shown by the meteorological logs received from ships in which he served, and he thus took up his new appointment with a first-hand knowledge of what was required of an observer at sea, and a strong desire to make the work at sea not only of scientific value to the professional meteorologist ashore but of sound practical value to the navigator himself in the daily performance of his duties. He worked unceasingly throughout his tenure of office with this object in view.

All meteorological work at sea had ceased during the four war years so that Commander Brooke Smith, on taking up his new appointment, had to start afresh in obtaining the interest of the shipping community in marine meteorology. Starting at the beginning, he realized that if a high standard of observation was to be maintained in future years, early training would be essential. A Cadet's meteorological log was therefore drawn up, to be kept at the three

Cadet establishments, *Conway*, *Worcester* and *Pangbourne*. By making frequent visits to the larger ports, and giving lectures on the value of marine meteorology to both shipowners and ships' officers, he was most successful in building up a new Observing Fleet and Voluntary Corps of Marine Observers. By his visits to the ports he was also able to obtain a consensus of nautical opinion as to what steps should be taken to provide the mariner with meteorological information that would be of practical assistance in day-to-day navigation. Hitherto, the work at sea had consisted of keeping meteorological log for climatological purposes only, but with the then rapidly growing use of radio at sea it became possible to apply ships' observations to synoptic meteorology. He drew up a scheme whereby ships when within range of coast stations regularly transmitted their reports to WEATHER LONDON for use in the Forecasting Division of the Meteorological Office. A weather bulletin was also broadcast to all shipping on both long and medium waves from a powerful British coast station. This bulletin included reports of weather observed at selected shore stations and by ships in the eastern Atlantic. With such reports at their disposal, ships were encouraged to plot their own simple synoptic charts and to deduce from them the probable change of weather that they were likely to experience as they proceeded on their course during the next twelve hours. Ships were also encouraged to broadcast radio weather messages at regular intervals for the benefit of " All Ships ", in all oceans of the world, so that all in turn could draw a synoptic chart from the data received, and so keep themselves weatherwise. This scheme worked so successfully that an extension of it, known as the " selected ship scheme", was adopted by the International Meteorological Organization and was brought into use by all maritime nations in 1930. To assist the Voluntary Corps of Marine Observers in obtaining the fullest advantage from the " selected ship scheme ", Captain Brooke Smith published a book for their use, " Wireless and weather, an aid to navigation".

It had been the practice, for many years, to publish articles of interest on the backs of the old monthly meteorological charts of the oceans, then supplied to all observing ships. With the advances made in meteorology and the keen interest evinced by marine observers in the subject, this means of keeping them informed was no longer considered adequate. A magazine, the *Marine Observer*, devoted to marine meteorology and written chiefly for the benefit of marine observers was brought into being in 1924, a particular feature in each number being a section termed " The marine observers' log", in which were published observations of natural phenomena of every description recorded at sea by individual observers, thus providing a means whereby mariners might pass on their experiences to others.

Another branch of the work which Captain Brooke Smith considered of primary importance was the more exact representation of the set and drift of the surface currents of the oceans, knowing that so many fine ships had been lost because of insufficient knowledge of the vagaries of currents. By interesting marine observers in this matter and encouraging them to forward observations of current, he was able to lay the foundation of the modern method of combining current data statistically and publishing the results in the form of atlases.

The observations recorded in ships' meteorological logbooks were originally extracted by hand into appropriate data books, and with the gradual increase of the Observing Fleet this method was found to be very slow and laborious.

On Commander Brooke Smith's attention being drawn by his scientific officer, Mr. C. S. Durst, to the possibility of using Hollerith machines to extract the data, he was quick to grasp its significance, with the result that the Hollerith method of data extraction was introduced in the Marine Branch in 1921. Without this foresight it would have been impossible to make the computations necessary for the meteorological atlases of all oceans, which were produced, and found so valuable, during the recent war.

Captain Brooke Smith also wrote and published a manual, especially for the use of seamen, entitled "A Handbook of weather, currents and ice", which has been largely used by personnel in the Merchant Navy. A Younger Brother of Trinity House, he was promoted to Captain, Royal Naval Reserve, in 1923. He was also a Founder Member of the Honourable Company of Master Mariners. He retired from the Meteorological Office in December 1938 on reaching the age of 60. During the whole of his 19 years of service as Marine Superintendent he worked unremittingly to achieve the aim which he had so much at heart, to assist seamen to make themselves proficient in the application of meteorology and sea-surface current information in the interests of safe and economical navigation.

Both the Meteorological Office and his brother seamen owe much to the work of one who was himself, first and foremost, a practical seaman, proud of his profession and zealous in advancing its standard of attainment in every way. His passing will be deeply regretted by all who knew him.

J. HENNESSY

WEATHER OF FEBRUARY 1951

Mean pressure was above 1020 mb. over an area covering part of western Canada, the eastern half of the United States, the Azores and part of Morocco. It was below 1000 mb. in an area west of southern Norway which included Iceland and the northern half of the British Isles, and extended nearly to southern Greenland, the mean being lowest (about 994 mb.) to the south-westward of the Faeroes.

It was above the average for February at the Azores, north-westward of the Azores and over the eastern half of the United States, the excess exceeding 10 mb. from Newfoundland eastwards to about 35°W.; there was also an excess around Spitsbergen and between Spitsbergen and the Gulf of Finland. Between the areas of excess there was one of substantial deficit, comprising nearly all the region between Greenland and the north coast of Africa, and exceeding 10 mb. south-westward of the Faeroes, over the British Isles and part of France.

In the British Isles the month was unsettled and rather cold, with frequent snow or sleet showers in some parts, particularly on high ground. It was wet except in the north-west, the rainfall being particularly heavy in the south-east. Conditions were generally unsettled until the last two days.

From the 1st to the 3rd a depression moved north-north-east from the south of Iceland, and troughs of low pressure crossed the British Isles. Rain, sleet or snow occurred and rainfall was moderately heavy in some areas on the 2nd and 3rd. On the 4th an exceptionally deep depression moved across Ireland to the Irish Sea and then turned north-north-west to the south of Iceland. Pressure

fell to 942·3 mb. at 1500 at Cork, a value which is probably very near to the minimum sea-level pressure attained in this depression, and is the lowest ever recorded in the British Isles in February. The readings of 951·7 mb. and 961·2 mb. at Ross-on-Wye and Kew Observatory respectively were the lowest in February during their long records. Widespread severe gales occurred in the British Isles on the 4th and 5th and precipitation was heavy on the 4th; 2·35 in. was recorded at Glen Tanar on Deeside. Showery weather, with long sunny periods locally, prevailed on the 5th and 6th. On the 7th another depression west of Ireland moved east and later north-east, followed by a secondary disturbance on the 8th off the south-west coast moving east-north-east. Precipitation on the 8th was heavy locally in the south of England. From the 10th to the 15th a depression situated initially off Brittany moved a little south and troughs or secondary depressions moved north-north-west or north from the south of France. Rain, sleet or snow occurred at times and thunder was recorded locally on the 12th and 15th. A trough off the south-west coast which followed caused considerable rain and local thunder. On the 16th a depression developed off north-west Ireland which then moved north-east and deepened, while on the 17th a wave depression approached the mouth of the English Channel and moved quickly east-north-east. Gales were recorded in the west and north and precipitation was heavy in some areas; 2·65 in. was recorded at Dundonnell House in north-west Ross-shire, and 2·45 in. at Kinlochquoich in Inverness-shire; snow blizzards swept the counties of Perth, Inverness and Argyll. Showers and local thunderstorms occurred on the 18th and 19th followed by moderately heavy rainfall in the south of England on the 20th caused by a small secondary depression moving quickly east-north-east. A complex area of low pressure to the west and north-west of the British Isles then moved east to the North Sea and showery weather prevailed, with long sunny periods. Showers also occurred on the 23rd and 24th associated with a small depression off the north-west coasts moving south-east in the northerly air stream, and on the 25th and 26th a trough of low pressure moving south-east across the country caused further precipitation. In the rear of this trough a ridge of high pressure built up over the British Isles and moved south; the closing days of the month were mainly fair apart from local fog. This was the fourth consecutive month with mean temperatures below the average. The lowest screen minimum temperatures included 20°F. at Kielder Castle on the 21st, 15°F. at Dalwhinnie on the 3rd and 24°F. at Aldergrove on the 10th and Ballykelly on the 15th.

The general character of the weather is shown by the following provisional figures:—

	Air Temperature			Rainfall		Sunshine
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	55	20	−0·9	186	+5	96
Scotland	54	15	−2·1	103	+3	96
Northern Ireland ...	53	24	−3·3	113	+3	120

RAINFALL OF FEBRUARY 1951

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	5·04	302	*Glam.*	Cardiff, Penylan ...	4·49	13
Kent	Folkestone, Cherry Gdn.	5·72	282	*Pemb.*	Tenby	3·99	19
,,	Edenbridge, Falconhurst	7·20	326	*Card.*	Aberystwyth	1·68	6
Sussex	Compton, Compton Ho.	6·68	253	*Radnor*	Tyrmynydd	7·54	14
,,	Worthing, Beach Ho. Pk.	5·49	277	*Mont.*	Lake Vyrnwy	7·80	17
Hants.	Ventnor, Roy. Nat. Hos.	6·97	332	*Mer.*	Blaenau Festiniog ...	8·93	10
,,	Bournemouth	6·04	253	*Carn.*	Llandudno	3·35	17
,,	Sherborne St. John ...	6·21	284	*Angl.*	Llanerchymedd ...	4·41	17
Herts.	Royston, Therfield Rec.	3·75	244	*I. Man*	Douglas, Borough Cem.	3·08	9
Bucks.	Slough, Upton	5·03	296	*Wigtown*	Port William, Monreith	2·65	8
Oxford	Oxford, Radcliffe ...	3·45	210	*Dumf.*	Dumfries, Crichton R.I.	3·29	10
N'hants.	Wellingboro' Swanspool	3·25	202	,,	Eskdalemuir Obsy. ...	4·61	9
Essex	Shoeburyness	4·14	337	*Roxb.*	Kelso, Floors	2·02	11
,,	Dovercourt	3·73	294	*Peebles*	Stobo Castle	3·53	12
Suffolk	Lowestoft Sec. School ...	2·85	203	*Berwick*	Marchmont House ...	2·08	10
,,	Bury St. Ed., Westley H.	3·32	221	*E. Loth.*	North Berwick Res. ...	1·93	12
Norfolk	Sandringham Ho. Gdns.	2·37	144	*Midl'n.*	Edinburgh, Blackf'd. H.	1·93	11
Wilts.	Bishops Cannings ...	4·76	225	*Lanark*	Hamilton W. W., T'nhill	2·35	8
Dorset	Creech Grange... ...	7·27	254	*Ayr*	Colmonell, Knockdolian	3·36	8
,,	Beaminster, East St. ...	6·04	200	,,	Glen Afton, Ayr San. ...	4·50	10
Devon	Teignmouth, Den Gdns.	5·87	221	*Bute*	Rothesay, Ardencraig ...	2·76	6
,,	Cullompton	5·05	181	*Argyll*	Morvern (Drimnin) ...	5·15	9
,,	Ilfracombe	4·71	170	,,	Poltalloch	3·56	8
,,	Okehampton Uplands	7·70	176	,,	Inveraray Castle ...	5·56	8
Cornwall	Bude, School House ...	3·70	148	,,	Islay, Eallabus	3·78	9
,,	Penzance, Morrab Gdns.	5·64	169	,,	Tiree	4·01	11
,,	St. Austell	5·36	140	*Kinross*	Loch Leven Sluice ...	3·14	11
,,	Scilly, Tresco Abbey ...	4·40	158	*Fife*	Leuchars Airfield ...	2·61	14
Glos.	Cirencester	4·03	178	*Perth*	Loch Dhu	5·13	6
Salop.	Church Stretton ...	3·92	168	,,	Crieff, Strathearn Hyd.	3·66	10
,,	Shrewsbury	2·02	129	,,	Pitlochry, Fincastle ...	2·97	10
Worcs.	Malvern, Free Library	3·29	183	*Angus*	Montrose, Sunnyside ...	2·52	13
Warwick	Birmingham, Edgbaston	3·11	184	*Aberd.*	Braemar	4·82	16
Leics.	Thornton Reservoir ...	2·87	172	,,	Dyce, Craibstone ...	3·91	17
Lincs.	Boston, Skirbeck ...	3·08	211	,,	Fyvie Castle	3·74	16
,,	Skegness, Marine Gdns.	3·30	216	*Moray*	Gordon Castle	3·49	18
Notts.	Mansfield, Carr Bank ...	3·67	200	*Nairn*	Nairn, Achareidh ...	1·92	11
Derby	Buxton, Terrace Slopes	5·82	155	*Inverness*	Loch Ness, Garthbeg ...	2·75	8
Ches.	Bidston Observatory ...	2·19	130	,,	Glenquoich	6·59	6
Lancs.	Manchester, Whit. Park	2.12	110	,,	Fort William, Teviot ...	5·02	6
,,	Stonyhurst College ...	3·82	114	,,	Skye, Duntuilm ...	3·64	7
,,	Squires Gate	2·54	120	*R. & C.*	Tain, Tarlogie House ...	1·64	7
Yorks.	Wakefield, Clarence Pk.	2·77	162	,,	Inverbroom, Glackour...	5·69	11
,,	Hull, Pearson Park ...	2·42	146	,,	Applecross Gardens ...	4·60	9
,,	Felixkirk, Mt. St. John...	4·47	146	,,	Achnashellach	5·55	8
,,	York Museum	2·16	143	,,	Stornoway Airfield ...	3·09	7
,,	Scarborough	2·27	135	*Suth.*	Loch More, Achfary ...	5·83	8
,,	Middlesbrough... ...	1·85	142	*Caith.*	Wick Airfield	3·47	15
,,	Baldersdale, Hury Res.	3·32	110	*Shetland*	Lerwick Observatory ...	5·66	17
Norl'd.	Newcastle, Leazes Pk....	2·11	138	*Ferm.*	Crom Castle	3·46	11
,,	Bellingham, High Green	2·86	113	*Armagh*	Armagh Observatory ...	3·02	10
,,	Lilburn Tower Gdns. ...	2·84	143	*Down*	Seaforde	4·23	13
Cumb.	Geltsdale	2·45	94	*Antrim*	Aldergrove Airfield ...	2·02	6
,,	Keswick, High Hill ...	5·56	113	,,	Ballymena, Harryville...	2·76	9
,,	Ravenglass, The Grove	4·65	151	*L'derry*	Garvagh, Moneydig ...	3·66	11
Mon.	Abergavenny, Larchfield	6·53	205	,,	Londonderry, Creggan	3·47	10
Glam.	Ystalyfera, Wern House	6·41	125	*Tyrone*	Omagh, Edenfel ...	3·36	11